Reynolds Number for a Multi-Surfaced Sphere and Turbulence Intensity in a Wind Tunnel

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Introduction

Turbulence intensity is the variation of the velocity in respect to a static or reference value. It measures how much the velocity of the air fluctuates over time. For wind tunnels, the turbulence intensity from the tunnel itself should be as low as possible to mitigate any interference in data collection. Unwanted turbulence in a wind tunnel can largely cause inaccurate data during experiments. Turbulence screens in the wind tunnel and filleted edges in the test section help reduce this. For this experiment, a smooth and rough sphere was placed on a force-balance system to determine the Reynolds number drop-off region and to determine the turbulence intensity of the wind tunnel. This experiment is useful because it shows the difference in drag profiles between smooth and rough surfaces as well as verifies that the wind tunnel had a minimal turbulent effect on the data.

Results and Discussion

The experiment was performed in the ERAU closed-loop research wind tunnel. A smooth sphere measuring 8.57 inches in diameter was placed in the wind tunnel test section attached to a force balance. The force-balance system measured the drag force of the sphere during the experiment.

The sphere was subjected to a range of free-stream velocities ranging from 30ft/s to 200ft/s. The exact speeds used can be found in Table 1. By using the reference area, dynamic pressure, and

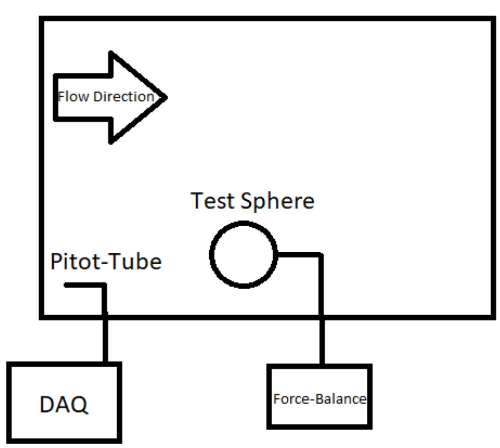

Figure 1. Schematic of Sphere in Test Section

drag force, the drag coefficient for each velocity can be found by rearranging the drag equation and solving for the coefficient of drag:

$$C_D = \frac{D}{qd^2} \tag{1}$$

Table 1. List of velocities and the corresponding drag coefficient for the smooth sphere.

Velocity (ft/s)	CD
30	0.387448
40	0.385337
50	0.387957
60	0.378993
70	0.349827
75	0.293038
80	0.249747
90	0.125494
100	0.129580
110	0.127975
120	0.124577
130	0.127796
140	0.134935
150	0.134502
175	0.133738
200	0.136937

Plotting this against the Reynolds number for the smooth sphere yields a curve with an asymptote around a Reynolds number of 385000. To increase the number of points in this range, more specific ranges of velocity were used. The specific velocities and their corresponding drag coefficients can be found in Table 2. The drag coefficients for the values in Table 2 were found using the same method as in Table 1.

Table 2. List of velocities for the asymptote with their velocities for a smooth sphere.

Velocity (ft/s)	CD
75	0.35016
78	0.331728
81	0.280345
84	0.235906
87	0.230643

This data was then superimposed in the region of the asymptote of the graph to give more data

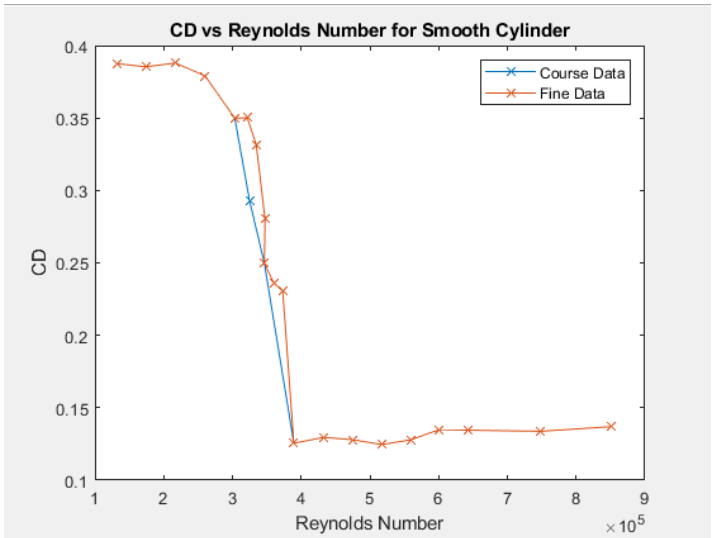

Figure 2. Plot of CD vs Reynolds number for the smooth sphere.

points in that region. As shown in Figure 2, the addition of the points to the asymptote gives more data around the point of interest. Plotting the fine sphere data against the rough sphere data shows a significant shift in where the drag coefficient drops as shown in Figure 3. The rough sphere causes the laminar flow to transition to a turbulent boundary layer along the rough

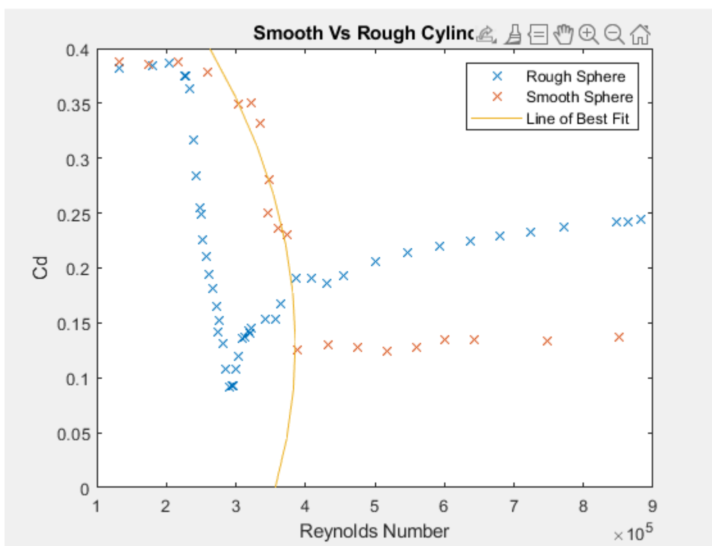

Figure 3. Plot of Rough Sphere and Smooth Sphere CD against Reynolds Number

sphere's surface. This causes the flow to stay attached and reduces the amount of pressure drag considerably. The asymptote at the lower Reynolds number shows the effects of the surface roughness on the drag. While the rough and smooth spheres have similar values for drag coefficients, the values of the Reynolds number that they occur at are very different.

To find the turbulence intensity of the experiment, the Reynolds number at a CD of 0.3 must be found. By applying a second-order polynomial fit to the experimental data of the smooth sphere, a line of best fit was found and plotted in Figure 2. This best fit line only takes into account the data points along the asymptote, increasing the accuracy of the fit. When graphing the best fit line at a CD of 0.3, the corresponding critical Reynolds number found was 337000. To find the turbulence factor, equation 2 was used.

$$TF = \frac{385000}{Re_{crit}} \tag{2}$$

The turbulence factor for this experiment was found to be 1.14. Using Figure 4, the free-stream turbulence percentage is approximately 0.17%. According to the lab manual, the free-stream turbulence found previously for the wind tunnel was 0.1%. This gives a 41.2% error, which is quite high. Some possible reasons for the error would be a relatively inaccurate best fit line and different test conditions for the fine data. The best fit line could be improved by increasing the order of the polynomial used. In the case of the test conditions, the fine data was taken with slightly different test conditions which may have skewed the Reynolds number value.

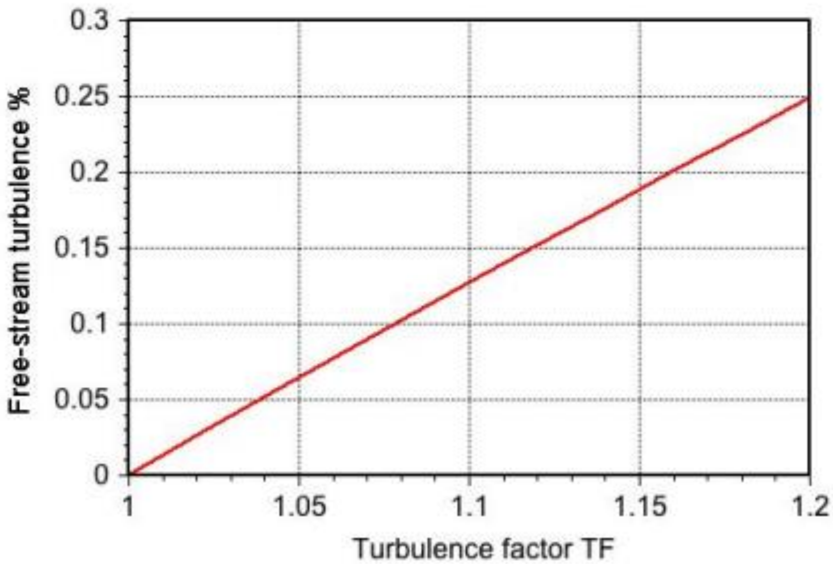

Figure 3: Turbulence Factor vs Free Stream Turbulence Percentage.

Conclusions

In this experiment, a rough and smooth sphere was subjected to the same free-stream velocities. It was proven that the rough sphere’s boundary layer was able to stay attached to the surface much more easily than the smooth sphere, resulting in the drag coefficient shifting at a much lower Reynolds number. Using this data, the experimental turbulence factor and the corresponding free-stream turbulence percentage were found. The turbulence percentage was 41.2% higher than previously measured in the wind tunnel, which may be due to differences in test conditions and inaccurate best-fit line for the data.

References

Department of Aerospace Engineering. *AE 315 Experimental Aerodynamics Lab 3.* Canvas

[Lab3_manual.pdf: AE 315 Experimental Aerodynamics Lab - SPR 2022 - In Person (instructure.com)]

Department of Aerospace Engineering. *RoughSphere.* Canvas

[RoughSphere.csv: AE 315 Experimental Aerodynamics Lab - SPR 2022 - In Person (instructure.com)]

MATLAB Code

```
clear;
clc;
close all


%Pull in data
data=readtable("022422_145120_Group1_Test1.csv");
finedata=readtable("Combined Data.xlsx");
roughdata=readtable("RoughSphere.csv");

%Set Smooth Variables
qinf_smooth=data.DynamicPressure;
D_smooth=data.WAFBCDrag;
diameter=8.57;
Reynolds_smooth=data.ReynoldsNumberPerFt*(8.57/12);

%Set Smooth_Fine Variables
qinf_smooth_fine=finedata.DynamicPressure;
D_smooth_fine=finedata.WAFBCDrag;
Reynolds_smooth_fine=finedata.ReynoldsNumberPerFt*(8.57/12);

%Set Rough Variables
qinf_rough=roughdata.q_psi_;
D_rough=roughdata.D_lbs_;
Reynolds_rough=roughdata.Re;


%Calculate the CDs for each case
for i=1:16
   Cd_smooth(i)=D_smooth(i)/(qinf_smooth(i)*(diameter^2));
end
```

```
for i=1:20
   Cd_smooth_fine(i)=D_smooth_fine(i)/(qinf_smooth_fine(i)*(diameter^2));
end

for i=1:46
    Cd_rough(i)=D_rough(i)/(qinf_rough(i)*(diameter^2));
end

%Plot the Course and Rough data for the smooth cylinder
plot(Reynolds_smooth,Cd_smooth,"-x")
title("CD vs Reynolds Number for Smooth Cylinder")
xlabel("Reynolds Number");
ylabel("CD")
hold on
plot(Reynolds_smooth_fine,Cd_smooth_fine, "-x")
legend('Course Data', 'Fine Data');
hold off

%Plot the Rough vs Smooth Cylinder
plot(Reynolds_rough,Cd_rough,"x")
hold on
plot(Reynolds_smooth_fine,Cd_smooth_fine,"x")
title("Smooth Vs Rough Cylinder")
xlabel("Reynolds Number")
ylabel("Cd")

%Calculate the best fit line
p_smooth=polyfit(Cd_smooth_fine(:,4:12),Reynolds_smooth_fine(4:12,:),2);
xval=linspace(0,0.4,10);
resmooth_crit=polyval(p_smooth,xval);

%Plot the best fit line
plot(resmooth_crit,xval);
legend("Rough Sphere", "Smooth Sphere","Line of Best Fit")

%Calculate the critical Reynolds number based on the best fit line.
reval=polyval(p_smooth,0.3)
```